Effect of shading on dry-matter production, yield and grain appearance quality of Vietnamese rice cultivars (*Oryza sativa* L.) in the paddy field

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(Course of Applied Plant Science)

Light intensity is one of the most important environmental factors to determine the growth and yield of rice. However, little information is known about the response of *indica* cultivars, especially Vietnamese cultivars to shading conditions. In this study, a field experiment was conducted in 2015 to determine the response of Vietnamese cultivars to shading condition during the grain filling period. Fourteen Vietnamese cultivars were covered by black cloth (50% shading treatment) after the heading stage in the field conditions. Grain yield of fourteen Vietnamese cultivars in shading condition fell to about 32.2-65.0% of the natural light condition. The most sensitive cultivars to shading are 'Jasmine 85' and 'OM2395', of which the grain yield decreased to 65.0 and 59.8% of natural light condition, respectively. The shaded yield decreased corresponding to the reduction in crop growth rate (CGR) and yield components, especially in the percentage of filled grain due to the increase in spikelet sterility. Shading increased the percentage of immature grains in all cultivars. Shading induced an increase in the percentage of chalky and green grains, which was largest in 'OM2517' and 'OM5451', respectively. Clearly, shading depressed both grain yield and the appearance quality of brown rice in Vietnamese cultivars, similarly reported in previous studies with Japanese cultivars.

Key words : Crop growth rate, Dry matter production, Grain appearance quality, Shading, Vietnamese cultivars.

Introduction

Light is the main energy source for plant photosynthesis and is an environmental signal used to trigger growth and structural differentiation in plants[2]. Without light, the net photosynthesis rate shows a negative value, because of discharging CO_2 through dark respiration[11]. Therefore, irrigated rice production is influenced by solar radiation[25]. Spatial and temporal variation in solar radiation is one of the major factors that impacts rice's potential yield[5]. During the heading stage, rice is most sensitive to environmental conditions. The optimum solar radiation value during rice grain filling stage (about 30 days before harvest) is 200 h bright sunlight[13].

Under low irradiance conditions, the dry matter weight of panicle decreased, as a result of most of the dry matter produced being used to sustain the growth of leaves, culm and sheaths rather than being allocated to panicle[17]. When the rice was grown under low light from the initial heading to maturity stages, rice grain yield decreased markedly, due to the decrease in seed-setting rate and 1000-grains weight[10]. During the ripening period, the impaired translocation of carbohydrates from source to sink under shading conditions is yet another factor in high sterility[6].

Because low light conditions can damage rice production dramatically, light intensity has received increasingly attention from researchers worldwide. Unfortunately, few investigations into the effect of shading on Vietnamese rice cultivars during grain filling has been studied. The present study aims to investigate the effect of shading on growth, yield and dry matter production of Vietnamese rice cultivars.

Materials and Methods

1. *Rice cultivation and treatment*

Pre-germinated seeds of fourteen cultivars (Table 1) were sown in seedling trays to produce uniform seedlings on June 4, 2015. Crop management followed the Japanese standard cultural practices. Mature seedlings of 14 cultivars were transplanted at hill spacing of 15 cm and row spacing of 30 cm (22 hills m^{-2}) on June 29, 2015. Basal fertilizer was applied at the rate of 8 gN m^{-2} with slow release fertilizers (LP100D-80E, N-P_2O_5, K_2O=14-

Received October 3, 2016

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Table 1 Details on years of release in Vietnam and the pedigree of fourteen Vietnamese cultivars

No.	Cultivar	Year of release in Vietnam	Pedigree	Heading time (DAT)
1	OM2517	2004	OM1235/OMCS94	54
2	OM1490	1999	OM606/IR44592-62	57
3	OM9584	Unknown	OM6976/OM5451	60
4	OM2395	2004	IR63356/TN1	61
5	AS996	2002	IR64/*Oryza rufipogon*	61
6	OM5981	2010	IR28/AS996	62
7	OM6161	2009	C51/Jasmine 85	65
8	OM5451	2010	Jasmine 85/OM2940	71
9	OM6162	2009	C50/Jasmine 85	74
10	OM6600	2011	C43/Jamine 85//C43	74
11	OM7347	2010	Khaodawkmali/BL/BL	74
12	OM8923	2011	OM3536/AS996	74
13	Jasmine 85	1993	Peta/Taichung Native 1//Khaod	74
14	OM4900	2008	C53/Jasmine 85//Japonica	74

DAT ; days after transplanting.

14-14).

The treatment started after the first cultivar heading. During the grain filling period, 50% shading treatment (S) by covering the rice canopy with black cloth corresponding to a 50% reduction in full natural light. Plants grown in natural light (NL) taken as control.

2. *Growth and dry matter production*

For the monitoring of dry weight, four standard plants were sampled at heading and maturity stage. Plants were divided into four parts ; culm plus leaf sheath, leaf blade, dead leaf and panicle. All samples were oven-dried at 80℃ for 48 hours, and then their dry weights were measured.

From the plant dry matter weight measured as described above, CGR was calculated as the dry matter increase (g) m^{-2} day^{-1}.

3. *Yield and yield components*

At physiological maturity, 20 hills were sampled diagonally from each plot to determine grain yield (g m^{-2}) and yield components i.e., the number of panicles m^{-2}, spikelets $panicle^{-1}$, percentage of filled grains and 1000-grains weight (g). Panicle number was counted from 20 hills to determine panicle number m^{-2}. The grain yield was adjusted to the standard moisture 0.14 gH_2O g^{-1} (14%).

The percentage of sterile grains was determined as follows ; panicles were threshed and the filled and unfilled spikelets were separated by submerging in the specific gravity solution. The spikelets which sank with specific gravity $\geqq$1.06, $\geqq$1.0 and $<$1.0 g cm^{-3} were defined as filled grains, partially filled grains and sterile spikelets, respectively. The percentage of filled grains is a ratio of the number of filled grains to the total number of spikelets.

4. *Grain appearance quality*

Three replications (20-30 g) of brown rice from each plot were used for the assessment of grain appearance quality. The percentages of chalky grains, which contain more than 20% of white area (white belly, white center and white back), and green grains were determined by grain scanner (RSQI 10B, Satake Co., Japan).

5. *Statistical analysis*

Data of dry matter production, yield and yield components was analyzed as two-way completely randomized design. Tukey's least significant difference at a probability level of 0.5% and 10% was used to compare the differences between treatment and genotypes.

Results

1. *Crop growth rate*

To identify the factor affecting difference in dry matter production, we compared CGR between two treatments (Fig. 1). Significant difference in CGR between NL and S was observed in all cultivars. The CGR of all cultivars was significantly decreased from 0.64 to 13.29 g m^{-2} day^{-1}. The highest CGR was observed in 'OM8923' of NL, and the difference of CGR between NL and S was also largest (13.19 g m^{-2} day^{-1}) in this cultivar. In 'OM7347', 'OM6162', 'OM1490' and 'OM2517', the CGR in NL was larger than in S about 10 g m^{-2} day^{-1}.

2. *Dry matter production*

Shading had a strong effect on dry matter in the shoot

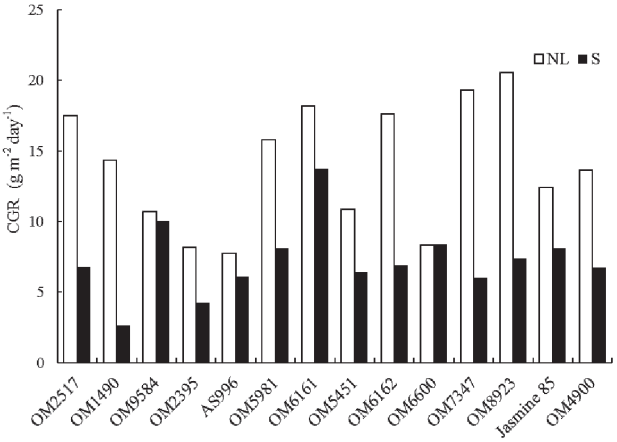

Fig. 1 Effect of shading on crop growth rate (CGR) during the ripening period in fourteen Vietnamese cultivars. (NL ; natural light plot, S ; shaded plot).

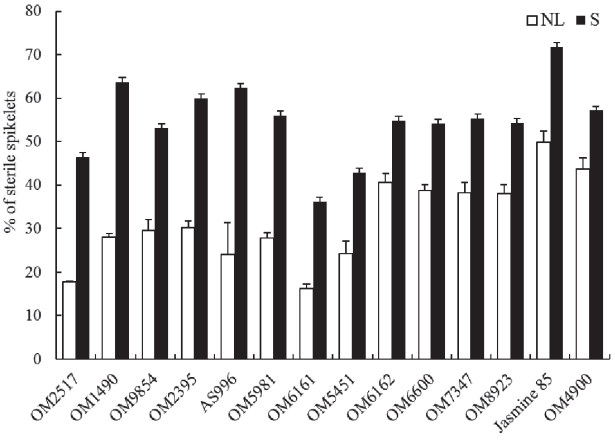

Fig. 3 Percentage of sterile spikelets in natural light and shaded treatment of fourteen Vietnamese cultivars (vertical bars indicate SD of means (n=3)). (NL ; natural light plot, S ; shaded plot).

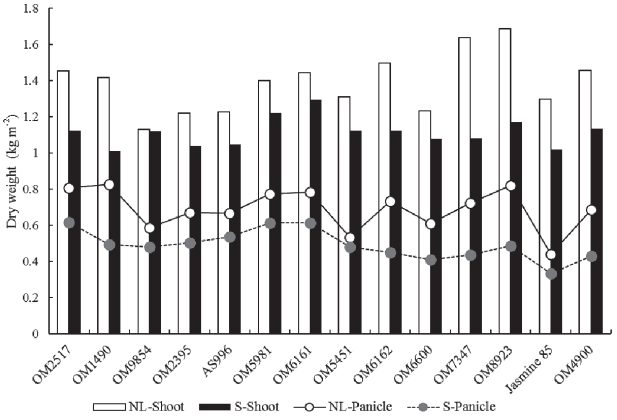

Fig. 2 Dry matter production at maturity stage under natural light and shaded plots of fourteen Vietnamese cultivars. (NL ; natural light plot, S ; shaded plot, Shoot : stems+panicles).

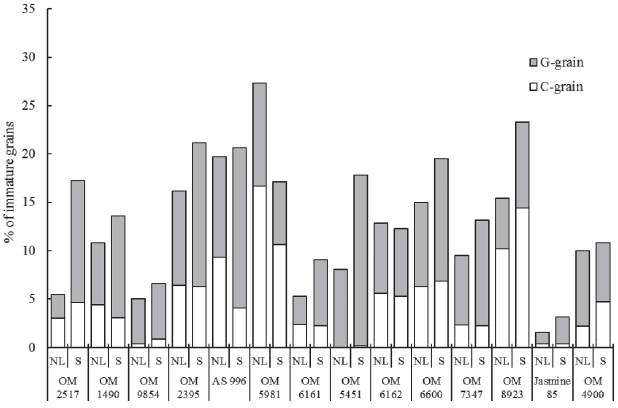

Fig. 4 Appearance quality of brown rice grains in fourteen Vietnamese cultivars under natural light and shaded treatment. (G-grain : green grains, C-grain : Chalky grains)

as well as in the panicle of all cultivars (Fig. 2). Under shaded condition, the dry weight of shoot in all cultivars decreased significantly. The difference in the shoot dry weight of fourteen Vietnamese cultivars between NL and S was about 0.02 to 0.52 kg m^{-2}. Also the panicle dry weight in S was 0.05 to 0.33 kg m^{-2} lower than NL. A significant reduction in the dry weights of shoot and panicle were observed under shaded condition.

3. *Yield and yield components*

Under shaded condition during the grain filling period, the spikelet sterility of fourteen Vietnamese cultivars increased dramatically (Fig. 3). The percentage of spikelet sterility of all cultivars in S was higher than NL within 13.4% to 38.4%. The strong impact of shading was recorded in 'AS996' and 'OM1490' with 38.4 and 35.7% increase in sterile spikelets, respectively. In all cultivars, the sterility percentage in shading treatment was over 35%, and the highest was in 'Jasmine 85' with 71.7% of sterile spikelets.

The effect of shading during the grain filling period on rice yield components and rice grain yield were observed in fourteen Vietnamese cultivars (Table 2). The percentage of filled grain, the number of spikelets per panicle and 1000-grains weight were hardly affected by shading compared with NL. The yield was dramatically decreased under shading condition in all cultivars. The difference of yield in each cultivar between NL and S was within 173.1-437.4 g m^{-2}. Grain yield of fourteen Vietnamese cultivars in shading condition reduced to about 32.2-65.0% of natural light condition. The most sensitive cultivars to shading were 'Jasmine 85' and 'OM2395' with 65.0 and 59.8% reductions in yield compared to natural light condition, respectively.

Table 2 Yield and yield components of 14 Vietnamese cultivars under natural light and shaded treatment

Cultivar	Treatment	No. of Panicles m^{-2}	No. of spikelets $Panicle^{-1}$	% of filled grains	1000-grains weight (g)	Grain yield ($g\ m^{-2}$)
OM2517	NL	295	111	80.8	26.3	695
	S	303	110	49.2	25.2	411
OM1490	NL	304	130	69.2	23.7	645
	S	362	116	32.9	23.0	316
OM9854	NL	267	114	67.0	25.3	519
	S	295	112	41.4	24.1	327
OM2395	NL	262	155	65.6	27.9	741
	S	281	115	34.1	27.0	297
AS996	NL	239	132	71.8	27.3	616
	S	259	125	33.1	26.4	283
OM5981	NL	252	139	67.6	25.7	608
	S	298	99	39.2	24.9	286
OM6161	NL	273	109	82.1	25.1	611
	S	275	102	59.6	24.8	415
OM5451	NL	336	102	71.8	25.4	622
	S	329	91	52.3	24.7	386
OM6162	NL	228	155	54.7	25.4	487
	S	243	120	40.0	23.8	277
OM6600	NL	221	146	57.8	25.1	467
	S	209	136	41.0	24.3	283
OM7347	NL	234	144	57.2	25.6	496
	S	235	134	378.8	24.3	297
OM8923	NL	326	117	59.8	26.6	607
	S	314	113	43.1	25.7	392
Jasmine85	NL	357	111	48.1	26.5	364
	S	211	104	23.8	24.3	127
OM4900	NL	243	134	52.5	25.5	436
	S	217	127	37.6	24.2	250
Significance	Cultivar	**	**	**	**	**
	Treatment	**	**	**	*	**

**, * : Significant at 0.01 and 0.05 levels based on ANOVA, respectively.

4. *Grain appearance quality*

The total percentage of green and chalky grains increased under shading compared to natural light (Fig. 4). The percentage of green grains of most cultivars in S was higher about 1.06-10.1% higher than that in NL. In some cultivars, the percentage of chalky grain increased 0.2 to 4.2% under shaded condition. The difference between NL and S was the highest in 'OM2517'. The percentage of chalky grains in 'OM2517' also increases under shaded condition. Among the cultivars, 'OM2517' was affected strongly on the grain appearance quality under shading condition. The grain appearance of Vietnamese cultivars was comparatively good quality, i.e., the percentage of immature grain usually less than 20%. In 'Jasmine', the percentage of immature grains is less than 5% in both S and NL treatment.

Discussion

The CGR is an index reflecting the increment of dry mass per unit leaf area and per unit land, thus it shows the real growth rate of crop canopy under any condition. In this study, the impact of shading on grain yield was investigated. The CGR of Vietnamese cultivars decreased significantly during grain filling period by shading, in which the solar radiation decreased to 50% of natural light (Fig. 1). This is similar to the finding of Chaturvedi et al. (1989)[1] in which CGR decreases under shading treatment. Under shaded conditions, leaves are not able to

receive enough light for the production of photosynthetic assimilates and they have a reduced ability to produce dry matter[4]. The grain yield of different genotypes was closely related to the CGR during grain filling periods. The higher CGR also lead to larger accumulation of non-structural carbohydrate in the culms and leaf sheaths during the grain filling period which correlated positively with the rapid translocation of photo-assimilates to the panicle[20, 22]. Cultivars having higher CGR during grain filling period produce a greater number of spikelets per unit land area[22]. The decline in CGR is a major factor leading to lower grain yield in Vietnamese cultivars.

Grain yield of rice is the product of different yield components i.e., the number of panicles per unit area, the number of grains per panicle, percentages of sterile grain and 1000-grains weight[25]. In the previous study of Ishibashi et al. (2014)[7] and Ishizuki and Saitoh (2012)[8] rice yield decreased markedly, when grown under low radiation (shading) from the initial heading to maturity stage, due to the significant decreases in the seed setting rate and 1000-grains weight. In this study, 1000-grains weight, the number spikelets per panicle and percentage of filled grain were also depressed by shading leading to a decrease in grain yield. In the report of Sridevi et al. (2015)[19], the low light causes increasing spikelet sterility which accords with the present study. The impaired translocation under subdued light of carbohydrates from source to developing grain during grain filling period is a factor causing high sterility[19]. Inappropriate accumulation of starch during grain filling under low light normally causes sterile and defective caryopses[24]. Under shading conditions, nutrient source organs (leaves + culms + sheaths) cannot provide adequate amounts of assimilate to meet the requirements of grain growth because of the impaired photosynthetic rate[9]. Post-heading shading caused a remarkable reduction in carbohydrate[16]. Additionally, low light inhibits the translocation of assimilates from source organs to sink organ (grains)[15]. Vijayalakshmi et al. (1991)[25] reported that the decline in rice grain yield was found to be caused by the increased number of partial filled and sterile grains under light stress condition. *OsSUT1*, a specific sucrose transporter plays an important role in maintaining the supply of photo-assimilates to the filling grain decreased by shading during grain filling stage, and led to decreasing transfer photo-assimilate from source to grains[8]. The shortage in photo-assimilates for filling grain is the main cause of the increase in partial filled grains under shading condition. It implies that under shaded conditions, grain dry weight decreases strongly and sterile spikelets increase dramatically, consequently the grain yield decreases.

The percentage of chalky and green grains increased under shading treatment during the ripening period (Fig. 4) giving the same results as Ishizuki and Saitoh (2012)[8], using Japanese cultivars. Green rice grains are the result of harvesting and drying while chloroplasts still remain in the pericarp of grain[14]. In the report of Sibing et al. (2004)[18] shading after heading extends the rice growth duration of the flag leaves. Thus, the increase in green rice grains in this study was also effected by extended growth period under low light condition. The chalky grain percentage in this research also increases in some cultivars (Fig. 4), giving the same results as Cheng-gang et al. (2015)[3]. In the report of Takata et al. (2010), the imbalance sink and source ability of carbon metabolism, as a result of high temperature at grain filling period, is considered one of the main causes of grain chalkiness[21]. Thus, the increase of chalky grains in the present study is a result of the imbalance sink and source caused by photosynthetic decline under low light conditions.

These results showed that low light stress closely effected both grain yield and grain appearance quality of Vietnamese cultivars.

References

1) Chaturvedi, G. S. and K. T. Ingram : Growth and yield of lowland rice in response to shade and drainage. Philipp J. Crop Sci., **14**, 61-67 (1989)
2) Chen, C.C., M. Y. Huang, K. H. Lin, W. D. Huang, and C. M Yang : Effects of light quality on the growth, development and metabolism of rice seedling (*Oryza sativa L*). Res. J. Biotech., **9**, 15-24 (2014)
3) Cheng-gang, L., L. Jia, W. Yan, X. Dan, D. Chun-bang and L. Tian : Low light during grain filling stage deteriorates rice cooking quality, but not nutritional value. Rice Sci., **22**, 176-206 (2015)
4) Ebrahin, A., M. Maral and R. B. Hamid : Effect of nitrogen fertilizer management on growth analysis of rice cultivars. Int. J. Biosci., **4**, 35-47 (2014)
5) Horie, T., M. Ohnishi, J. F. Angu, L.G. Lewin, L T. Tsukaguki and T. Matano : Physiological characteristics of high-yielding rice inferred from cross-location experiments. Field crops Res., **52**, 55-67 (1997)
6) IRRI : Weather and rice. pp. 93-101, IRRI, Los Banos (1986)
7) Ishibashi, Y., K. Okamura, M. Miyazaki, T. Phan, T. Yuasa and M. Inoue : Expression of rice sucrose gene *OsSUT1* in sink and source organs shaded during grain filling may effect grain yield and quality. Environ. Exp. Bot., **97**, 49-54 (2014)
8) Ishizuku, H. and K. Saitoh : Effect of shading and high temperature treatments on appearance quality of brown rice and

palatability of cooked rice. Sci. Rep. Fac. Agr. Okayama Univ., **101**, 25–32 (2012) (in Japanese with English summary)
9) Janardhan, K. V., K. S. Murty and N. B. Dash : Effects of low light during ripening period on grain yield and translocation of assimilates in rice varieties. Indian J. Plant Physiol., **23**, 163–168 (1980)
10) Liu, Q., X. Wu, B. Chen, J. Ma and J. Gao : Effects of low light on agronomic and physiological characteristics of rice including grain yield and quality. Rice Sci., **21**, 243–251 (2014)
11) Matsuo, T., K. Kumazawa, K. Ishihara, R. Ishii and H. Hirata : Science of rice plant (Volume (2), Physiology). pp. 508–606, Food and Agriculture Policy Research Center, Tokyo (1995)
12) Muchie, E. H., S. Hubbart, S. Peng and P. Horton : Acclimation of photosynthesis to high irradiance in rice : gene expression and interactions with leaf development. J. Exp. Bot., **56**, 449–460 (2005)
13) Murty, K. S and G. Sahu : Impact of low-light stress on growth and yield of rice. In Weather and Rice : Proceedings of the international workshop on the impact of weather parameter on growth and yield of rice, pp. 93–101, IRRI, Manila (1987)
14) Mutters, R. G., and J. S. Thompson : Rice quality handbook, pp. 9–12, University of California Agriculture and Natural Resources, (2009)
15) Nayak. S. K and K. S. Murty : Effects of varying light intensities on yield and growth parameters in rice. J Plant Physiol., **23**, 309–316 (1980)
16) Ota, Y. and N. Yamada : Effect of shading on sterility percentage in *indica* rice. Jpn. J. Trop. Agr., **9**, 15–18 (1965)
17) Ren, W. J., W. Y. Yang, G. Q. Fan and Z. H. Ma : Effect of low light on dry matter accumulation and yield of rice. J. Sichuan Agri. Univ., **20**, 205–208 (2003)
18) Sibing, D., D. Biyan, W. Dongyun and Z. Lei : Effect of temperature and light on the senescence of flag leaf and grain filling after rice heading. J. South China Natl. Univ., **1**, 117–121 (2004)
19) Sridevi, V. and V. Chellamuthu : Impact of weather on rice. Intl. J. of Appl. Res., **1**, 825–831 (2015)
20) Sun, Y, Y., Y. J. Sun, L. Chen, H. Xu and J. Ma : Effects of different sowing dates and low light stresses on crop. J. Anhui Agric. Sci., **34**, 4216–4218 (2012)
21) Takata, S., M. Sakata, M. Kameshima, Y. Yamamoto and A. Miyazaki : Varietal difference in the relation between the occurrence of white immature kernels caused by high temperature during the ripening period and the amount of basal nitrogen application in rice. Jpn. J. Crop Sci., **79**, 150–157 (2010) (In Japanese with English abstract)
22) Takai, T., S. Matsuura, T. Nishio, T. Ohsumi, T. Shiraiwa and T. Horie : Rice yield potential is closely related to crop growth rate during late reproductive period. Field Crops Res., **96**, 328–335 (2006)
23) Tian, L., R. Ohsugi, T. Yamagishi and H. Sasaki : Effects of weak light on starch accumulation and starch synthesis enzyme activities in rice at the grain filling stage. Rice Sci., **13**, 51–58 (2006)
24) Vijayalakhmi, C., R. Radhakrishnan, M. Nagarajan and C. Rajendran : Effect of solar radiation deficit on rice productivity. J. Agron. Crop Sci., **167**, 184–187 (1991)
25) Yoshida, S : Fundamentals of rice crop science, pp. 60–61, IRRI. Laguna, (1981)

圃場栽培したベトナム産水稲品種（*Oriza sativa* L.）の乾物生産，収量と玄米の外観品質

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光強度は，水稲の生育・収量を決定する最も重要な環境要因である．しかし，光強度の減少，すなわち遮光処理がインド型水稲品種，特にベトナム産品種の生育・収量に及ぼす影響に関する知見は限られている．本研究では，登熟期間の遮光がベトナム産水稲品種の乾物生産，収量と収量構成要素，玄米の外観品質に及ぼす影響を2015年に調査した．ベトナム産水稲14品種を圃場栽培を行い，最初に出穂が認められた品種の出穂期以降収穫期まで，群落上層を黒色寒冷紗（遮光率50％）を用いて被覆する，遮光処理を行った．ベトナム産14品種の収量は，遮光に伴い自然光条件に比較して32.2～65.0％の低下がみられた．遮光処理の影響が大きかった品種は ‘Jasmine 85’ と ‘OM2395’ で，それぞれ65.0，59.8％の収量低下がみられた．収量の低下には，登熟期の個体群成長速度，収量構成要素では穎花不稔の増加による登熟歩合の低下に起因していた．遮光処理はすべての品種で玄米の未熟粒割合を増加させた．遮光処理により，白未熟粒と青未熟粒の増加がみられ，その程度は白未熟粒が ‘OM2517’ で，青未熟粒が ‘OM5415’ で最も著しかった．以上の結果，遮光処理はベトナム産水稲14品種の収量と玄米の外観品質を低下させたが，その程度には品種間差があることが明らかになり，これらの傾向は日本産水稲品種で得られた結果と同様であった．

Received October 3, 2016
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